VH(bb) measurements: results and main limitations

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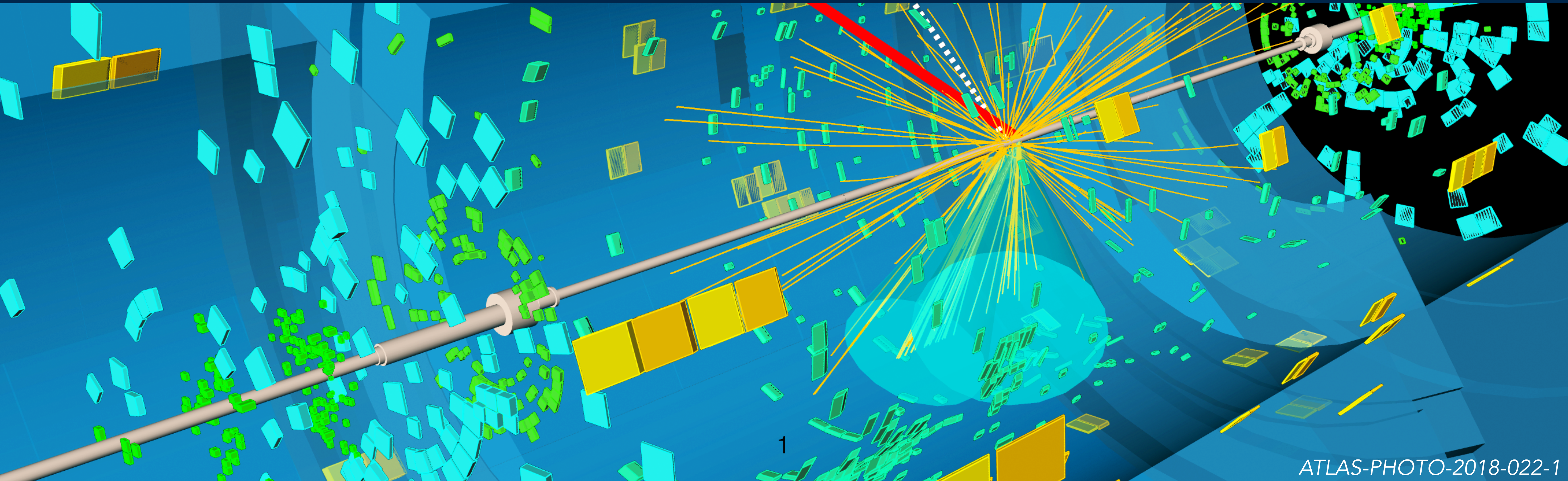

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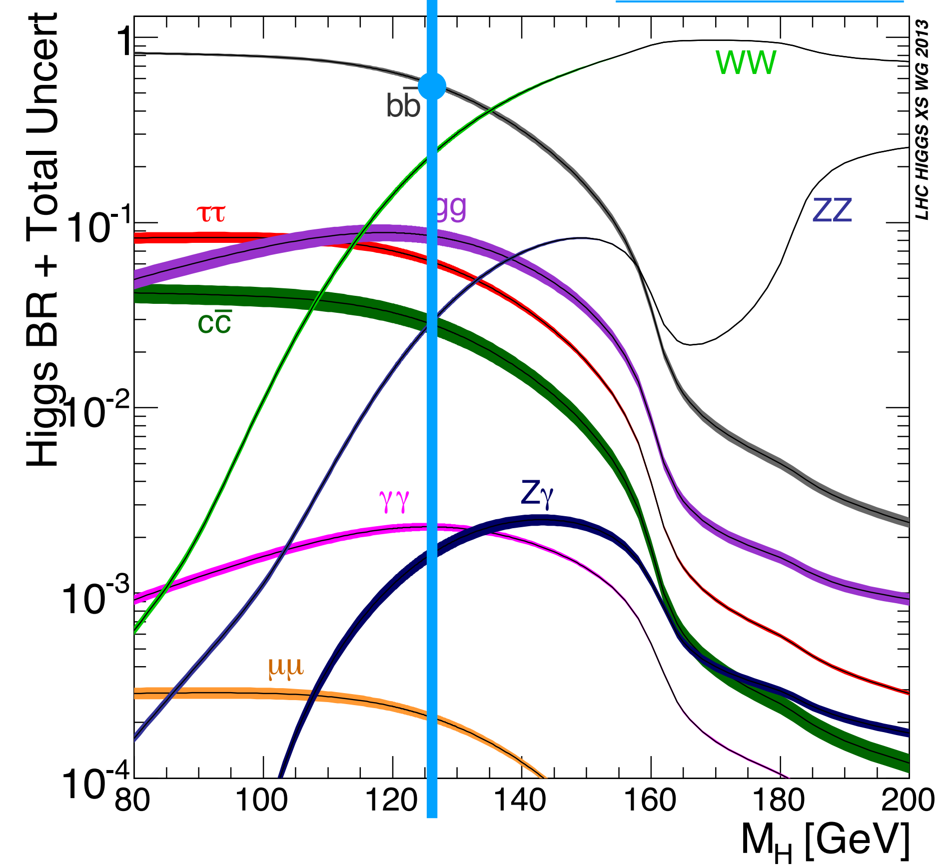
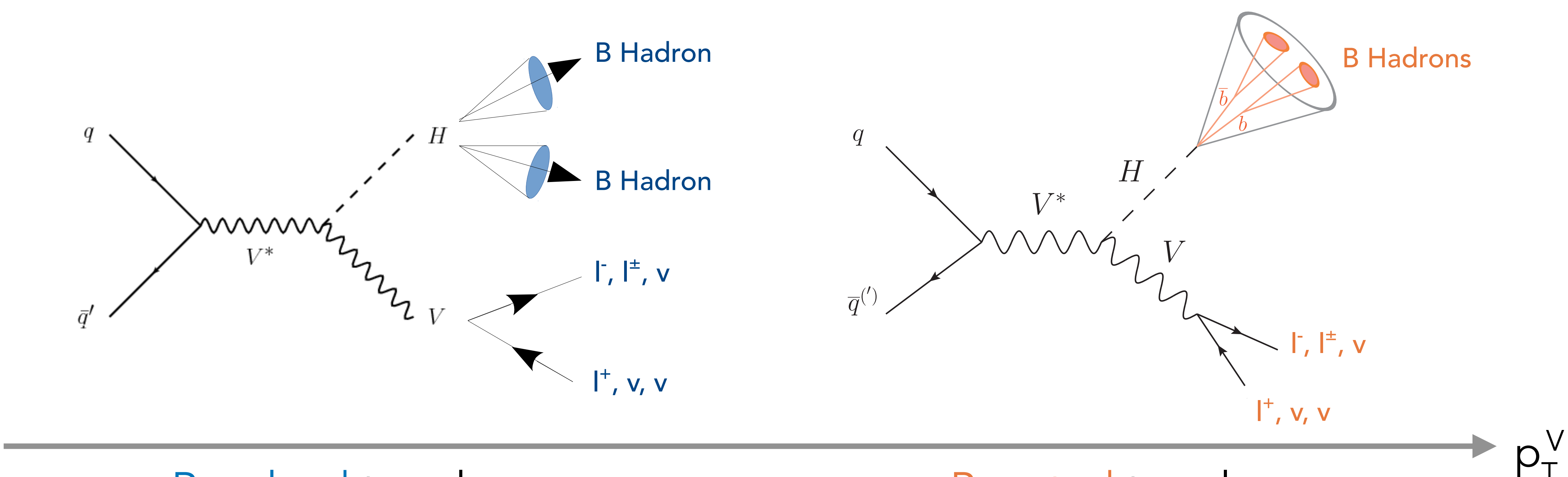
The Higgs boson and the VH channel

- after discovery, focus shifted on measuring H properties like the b-Yukawa coupling:
  - largest branching fraction H→bb ~ 58%
- associated production with a vector boson decaying to leptons (VH channel) to identify the process
  - events triggered on leptons or E_T^{miss}
  - 3 separate channels in which sensitivity is enhanced: 0, 1 and 2 leptons V decay modes

arXiv:1307.1347





Resolved topology

Boosted topology

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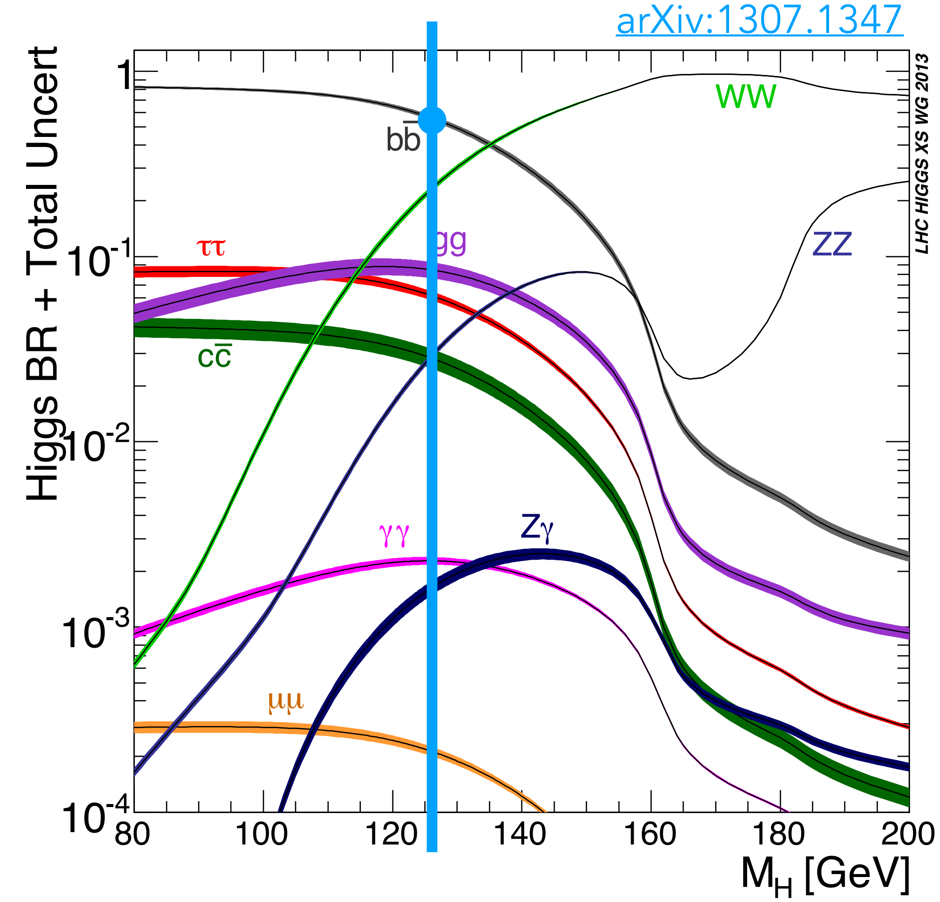
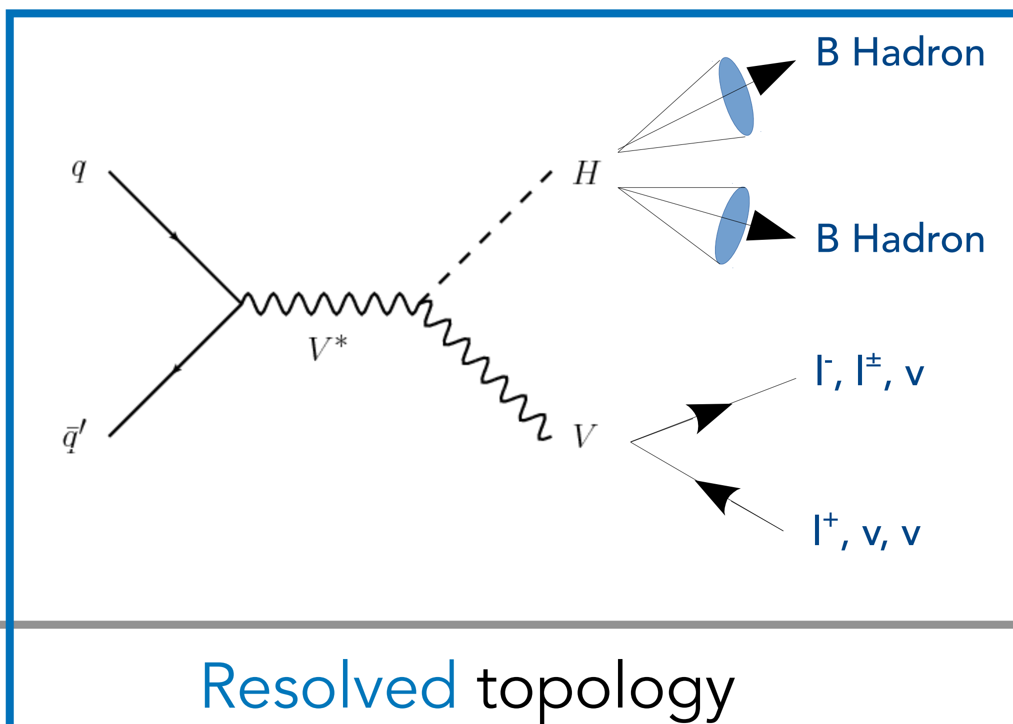
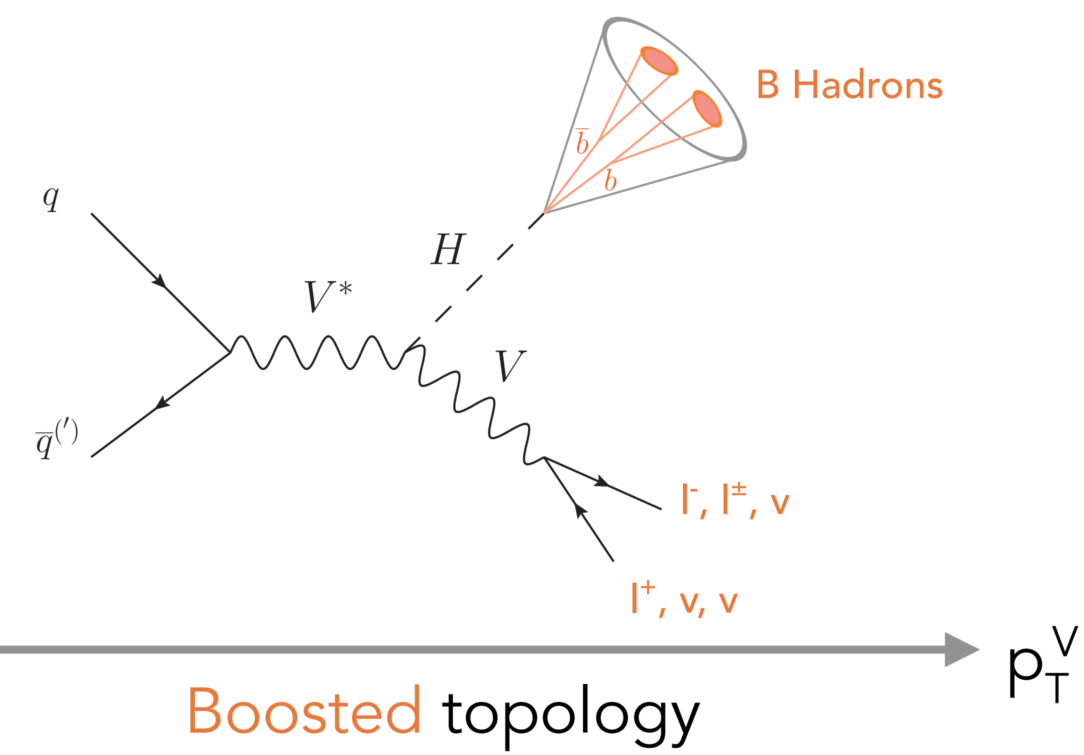
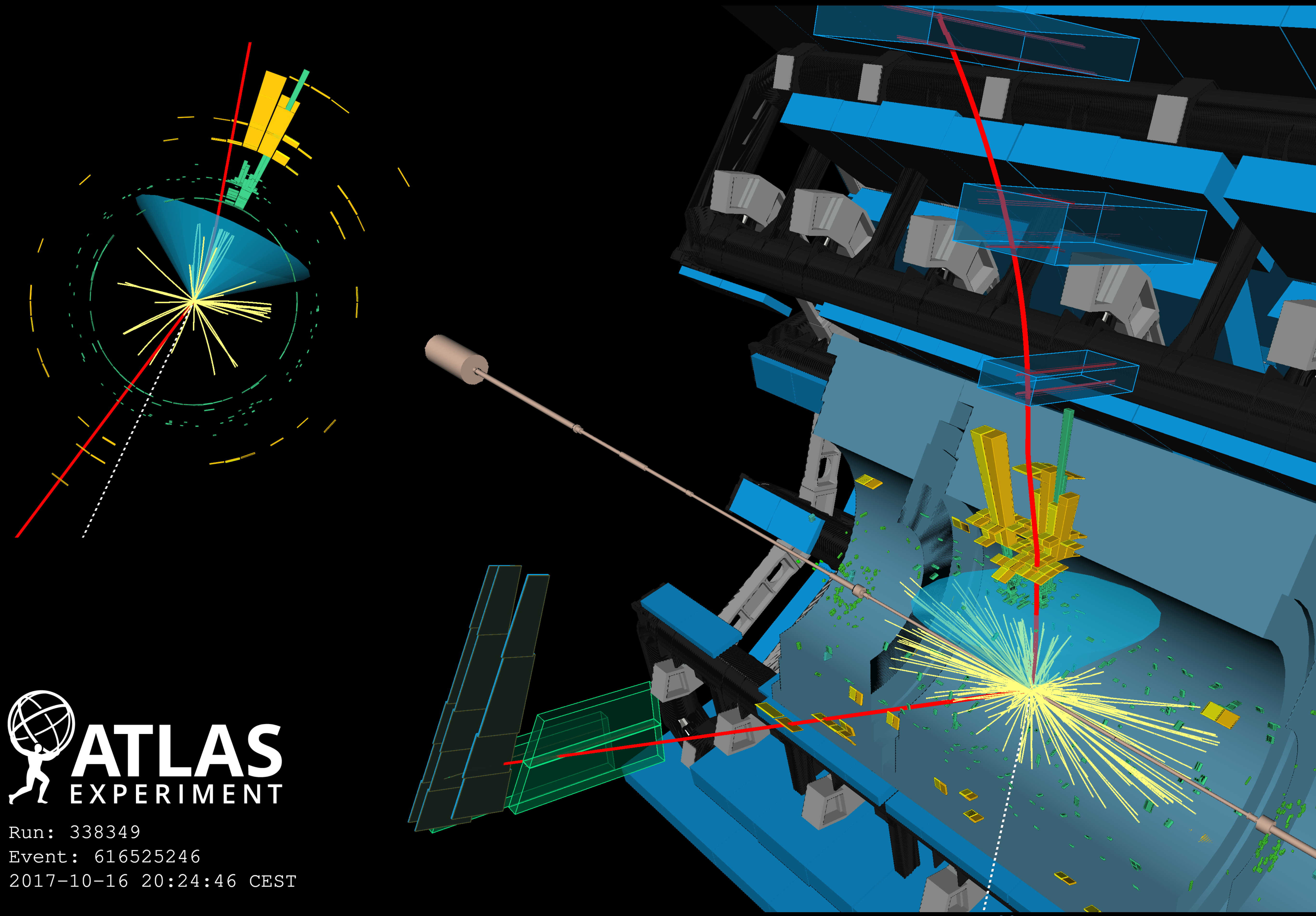






arXiv:2008.02508

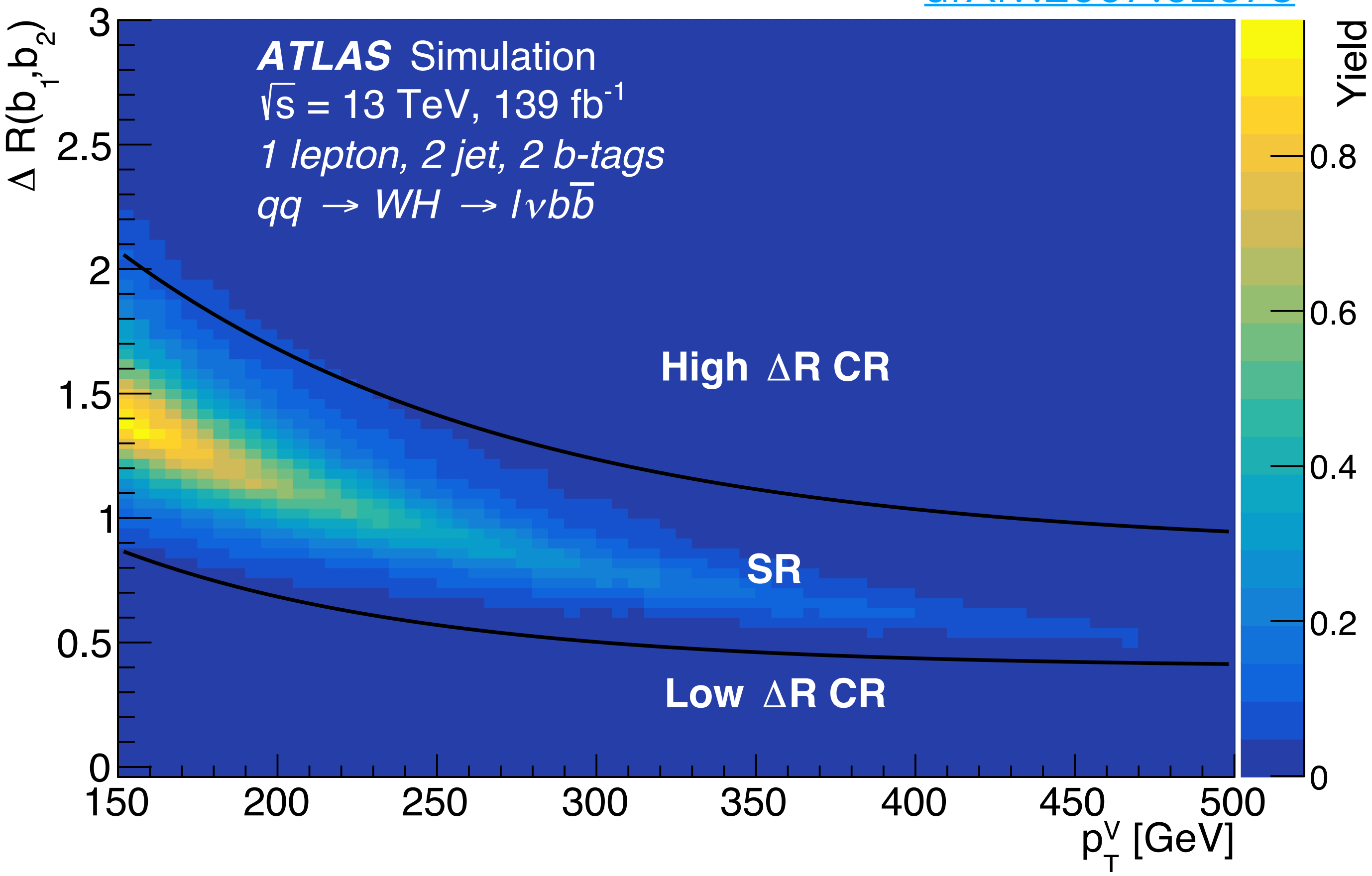


Boosted W(→μν)H(→bb) candidate event - m_{bb} = 116 GeV, p_T^V = 1.03 TeV

Event selection and regions definition

- **online triggers** used to identify candidate events
- **exactly two b-tagged jets** required - identified through MVA discriminant
- **channel specific cuts**:
  - to reduce fake E_T^{miss} in 0L
  - to enhance Z signal in 2L channel
- p_T^V **cut regions definition** - to enhance sensitivity [75,150] GeV, [150,250] GeV, > 250 GeV
- **functional cut on ΔR(b,b) vs** p_T^V defines Signal Region (SR) & Control Regions (CR)

arXiv:2007.02873



(1) plots from https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2018-51/#auxstuff

Analysis strategy

- residual backgrounds: V+heavy flavour (HF) jets & top quark processes
  - 2l channel dominated by Z+HF background

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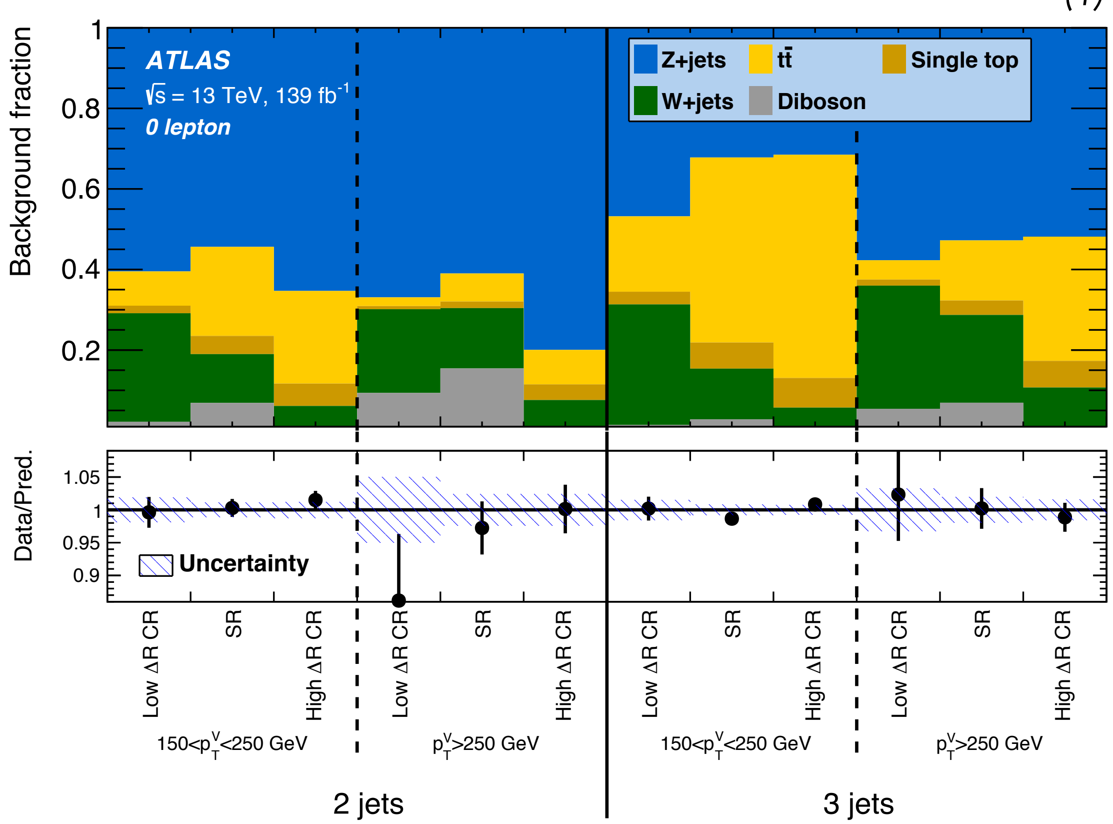

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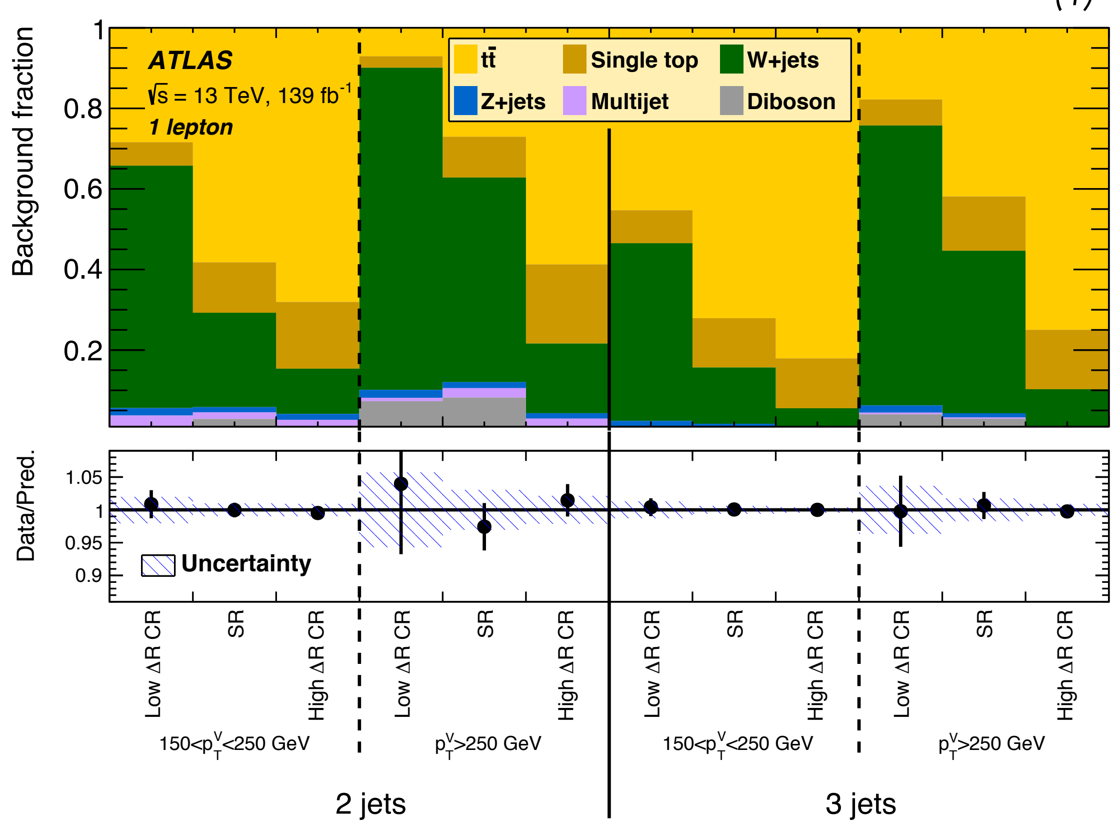

- multivariate discriminants (BDT) adopted to enhance sensitivity:
  - **BDT**$_{VH}$ separate VH(→bb) signal from background processes
  - **BDT**$_{VZ}$ discriminate VZ(→bb) process from VH & other backgrounds, used to <u>validate</u> the VH main analysis

Multivariate discriminant improvements

- new variables included w.r.t. previous iteration of the analysis to improve sensitivity

Variable	0-lepton	1-lepton	2-lepton
m_{bb}	$\times$	$\times$	$\times$
$\Delta R(\vec{b}_1, \vec{b}_2)$	$\times$	$\times$	$\times$
$p_{\mathrm{T}}^{b_1}$	$\times$	$\times$	$\times$
$p_{\mathrm{T}}^{b_2}$	$\times$	$\times$	$\times$
p_{T}^{V}	$\equiv E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	$\times$
$\Delta\phi(\vec{V}, \vec{bb})$	$\times$	$\times$	$\times$
$\mathrm{MV2}(b_1)$	$\times$	$\times$	
$\mathrm{MV2}(b_2)$	$\times$	$\times$	
$\lvert\Delta\eta(\vec{b}_1, \vec{b}_2)\rvert$	$\times$		
m_{eff}	$\times$		
$p_{\mathrm{T}}^{\mathrm{miss,st}}$	$\times$		
$E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	$\times$	
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		$\times$	
m_{T}^{W}		$\times$	
$\lvert\Delta y(\vec{V}, \vec{bb})\rvert$		$\times$	
m_{top}		$\times$	
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			$\times$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{S_{\mathrm{T}}}$			$\times$
$m_{\ell\ell}$			$\times$
$\cos\theta(\vec{\ell^-}, \vec{Z})$			$\times$
	Only in 3-jet events		
$p_{\mathrm{T}}^{\mathrm{jet}_3}$	$\times$	$\times$	$\times$
m_{bbj}	$\times$	$\times$	$\times$

arXiv:2007.02873

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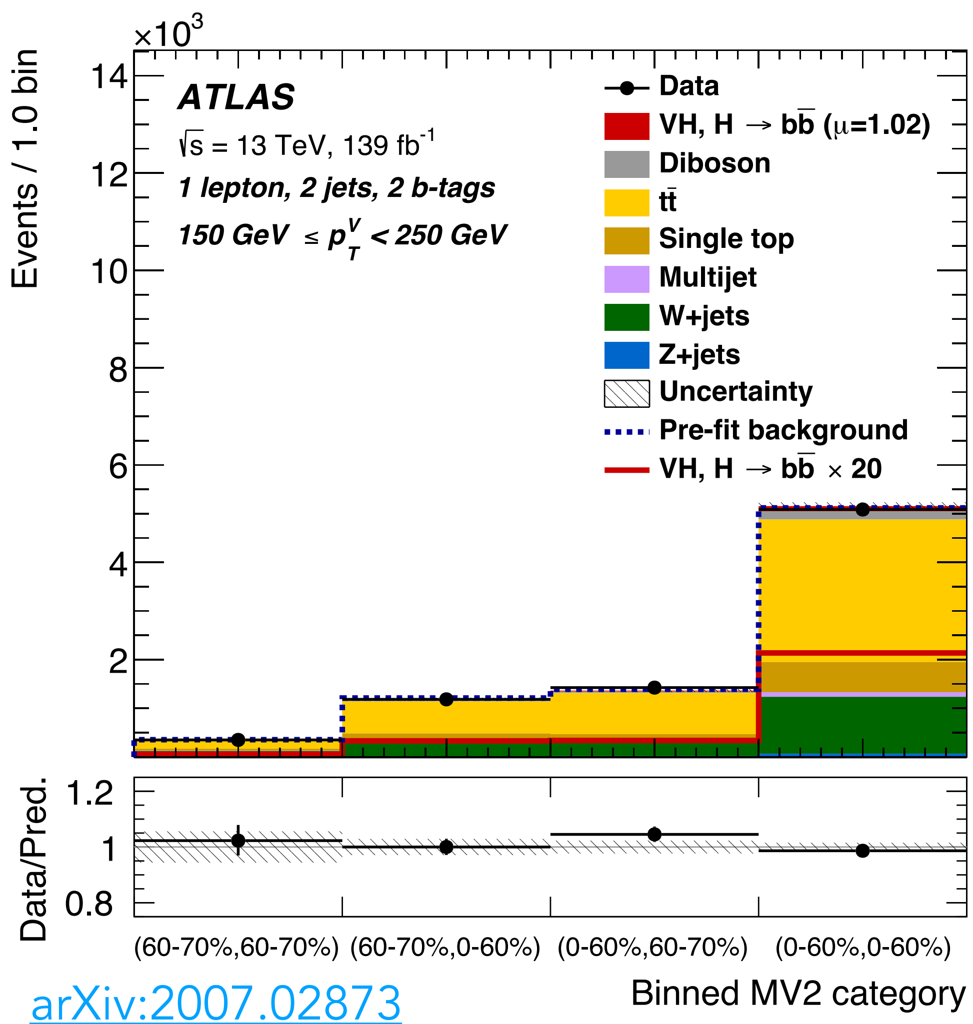
  - **MV2(b)**: binned b-tagging discriminant for b-jets improves the rejection of W→cq, tt and tW bkgs.



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$\Delta\phi(\vec{V}, \vec{bb})$	×	×	×
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m_{eff}	×		
$p_T^{miss,st}$	×		
E_T^{miss}	×	×	
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		×	
m_T^W		×	
$\lvert\Delta y(\vec{V}, \vec{bb})\rvert$		×	
m_{top}		×	
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			×
$E_T^{miss}/\sqrt{S_T}$			×
$m_{\ell\ell}$			×
$\cos\theta(\vec{\ell^-}, \vec{Z})$			×
Only in 3-jet events			
$p_T^{jet_3}$	×	×	×
m_{bbj}	×	×	×

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→ sensitivity improvement: + 7~10% (0, 1lep)

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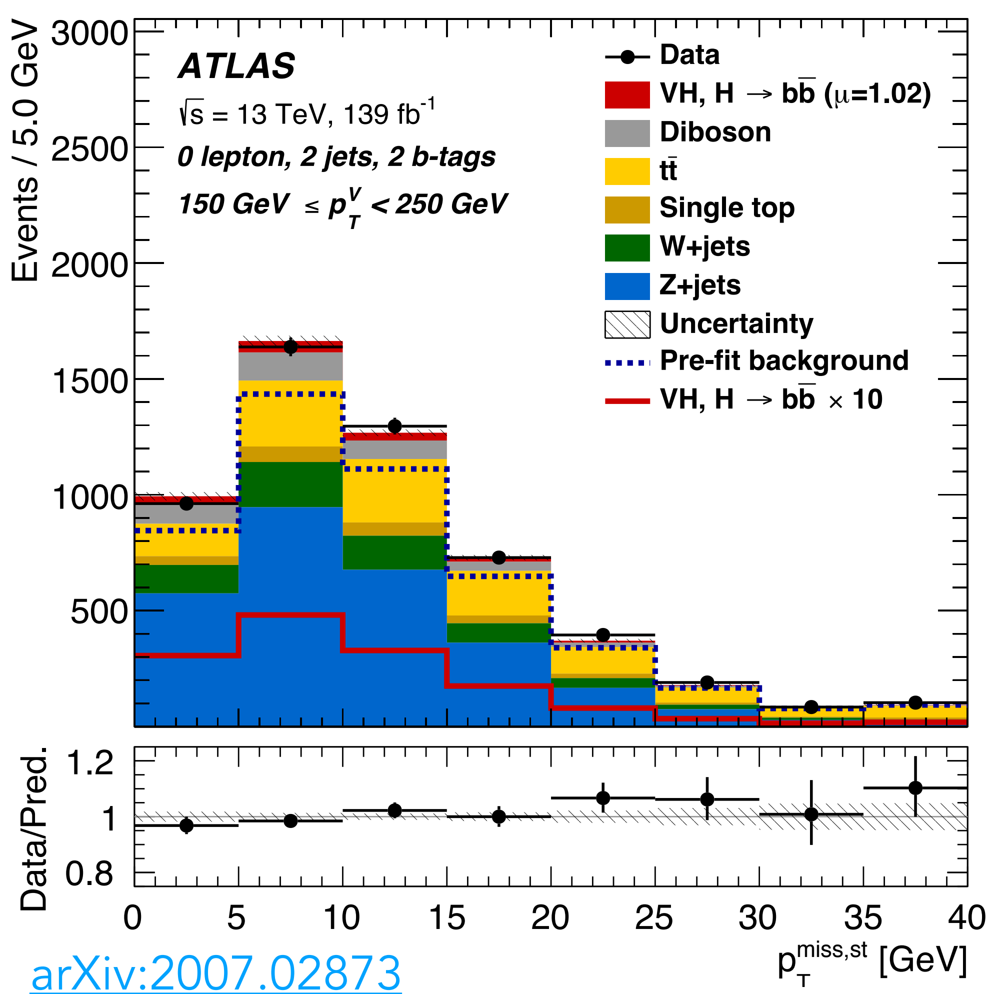
  - $p_T^{miss,st}$: reduce events with mis-reconstructed objects



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m_{eff}	×		
$p_T^{miss,st}$	×		
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m_T^W		×	
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$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			×
$E_T^{miss}/\sqrt{S_T}$			×
$m_{\ell\ell}$			×
$\cos\theta(\vec{\ell^-}, \vec{Z})$			×
Only in 3-jet events			
$p_T^{jet_3}$	×	×	×
m_{bbj}	×	×	×

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→ sensitivity improvement: + 2~3% (0 lep)

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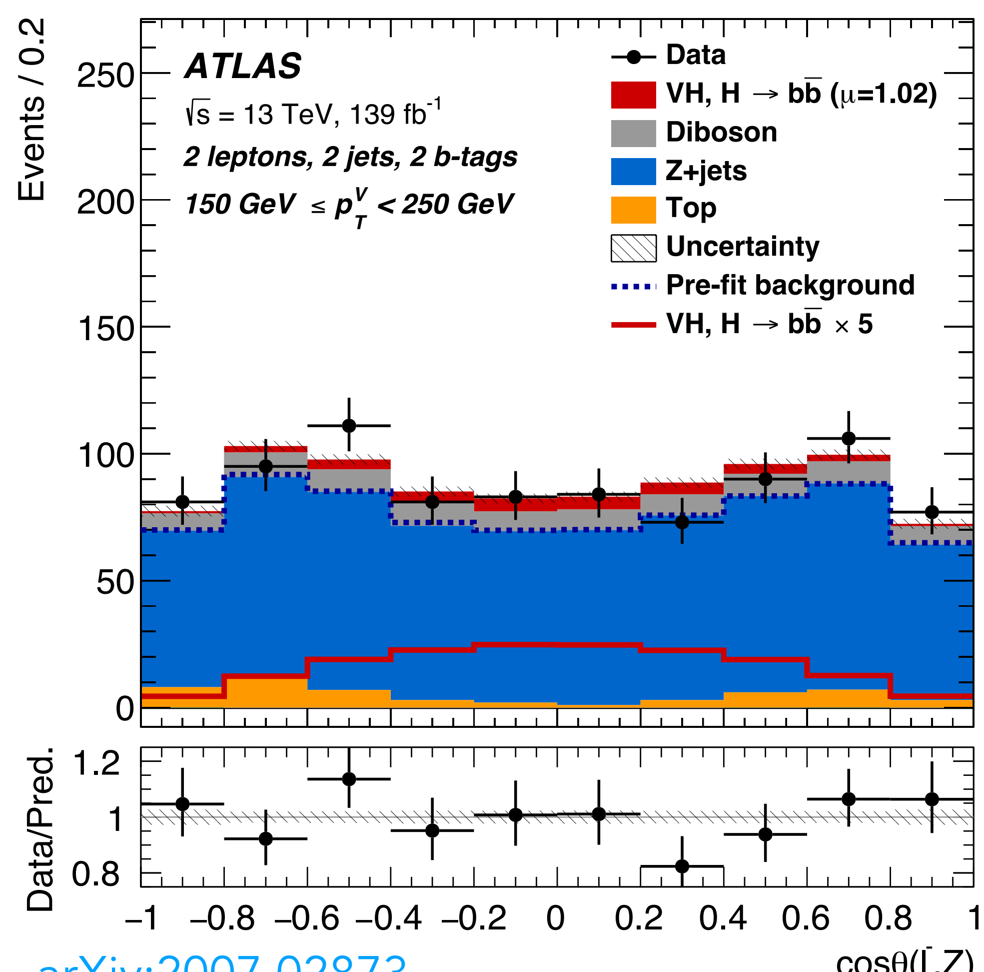
  - **MV2(b)**: binned b-tagging discriminant for b-jets improves the rejection of W→cq, tt and tW bkgs.
  - $p_T^{miss,st}$: reduce events with mis-reconstructed objects
  - **cosθ(l, Z)**: polarisation of the Z boson



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$\Delta R(\vec{b}_1, \vec{b}_2)$	×	×	×
$p_T^{b_1}$	×	×	×
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p_T^V	$\equiv E_T^{miss}$	×	×
$\Delta\phi(\vec{V}, \vec{bb})$	×	×	×
$MV2(b_1)$	×	×	
$MV2(b_2)$	×	×	
$\lvert\Delta\eta(\vec{b}_1, \vec{b}_2)\rvert$	×		
m_{eff}	×		
$p_T^{miss,st}$	×		
E_T^{miss}	×	×	
$\min[\Delta\phi(\vec{\ell}, \vec{b})]$		×	
m_T^W		×	
$\lvert\Delta y(\vec{V}, \vec{bb})\rvert$		×	
m_{top}		×	
$\lvert\Delta\eta(\vec{V}, \vec{bb})\rvert$			×
$E_T^{miss}/\sqrt{S_T}$			×
$m_{\ell\ell}$			×
$\cos\theta(\vec{\ell^-}, \vec{Z})$			×
Only in 3-jet events			
$p_T^{jet_3}$	×	×	×
m_{bbj}	×	×	×

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→ sensitivity improvement: + 7% (2 lep)

Fit strategy

- as discriminant variable the output of BDT is used for the 14 Signal Regions

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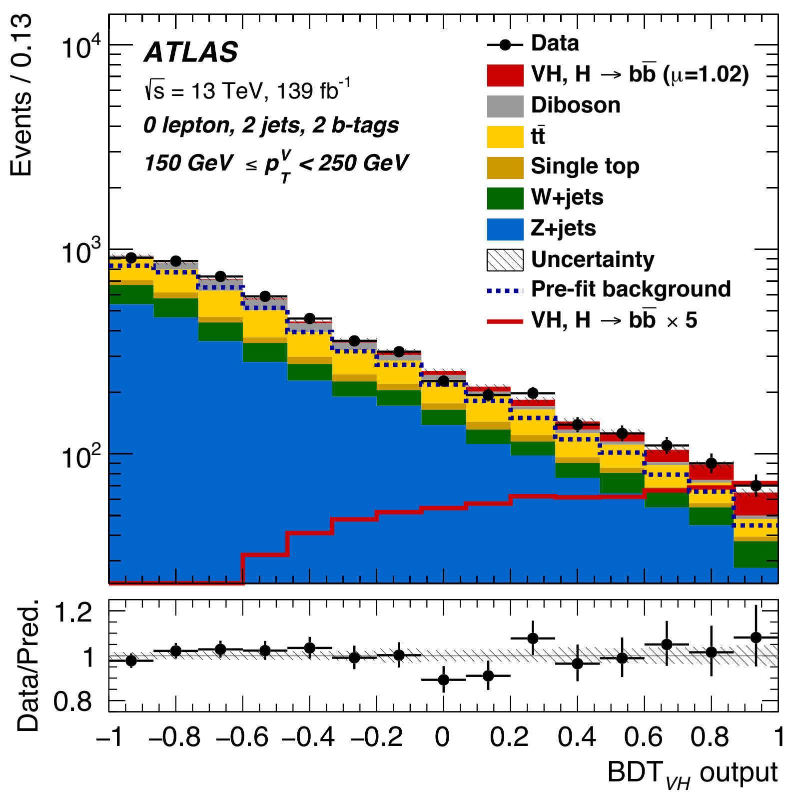

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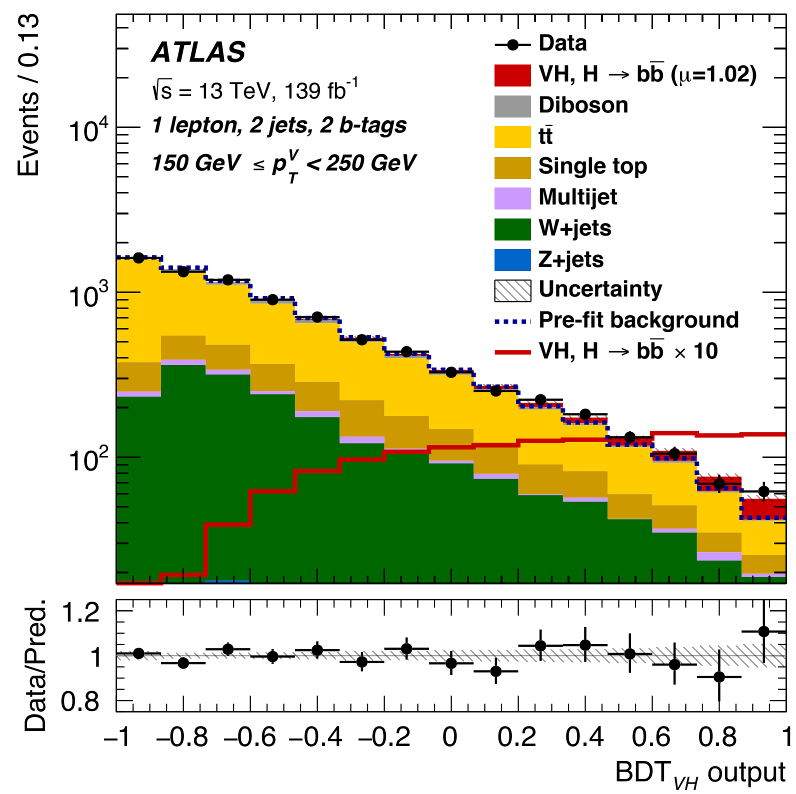

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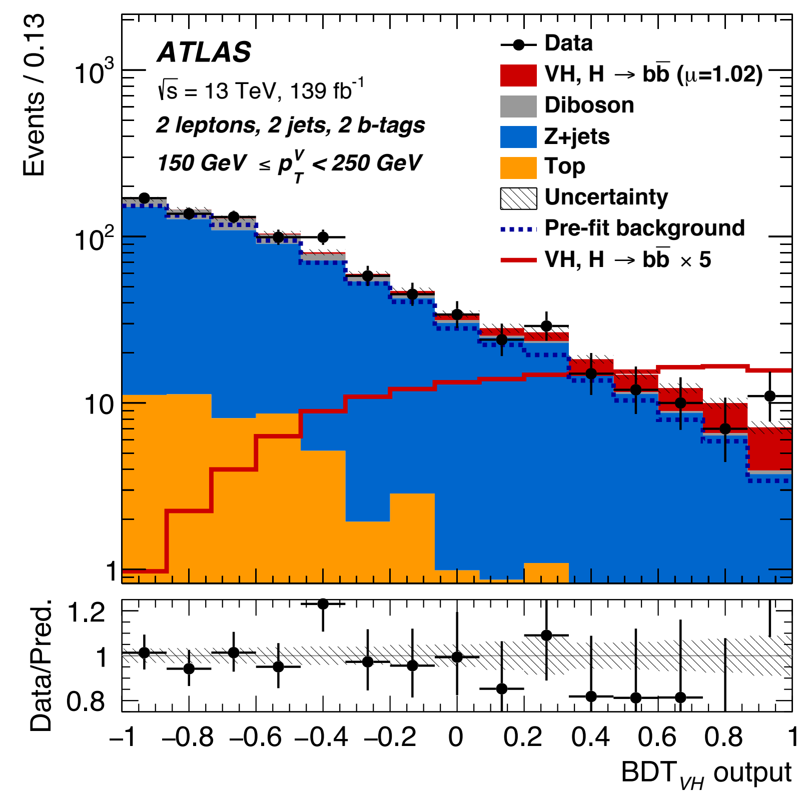

- high/low ΔR control regions event yields taken as inputs to the global likelihood fit
- floating normalisation in the fit of the main backgrounds - Z+HF, W+HF, tt
- experimental and theoretical systematic uncertainties included

(1) plots from arXiv:2007.02873

Modelling systematic uncertainties

- estimation relies on the comparison between the nominal MC sample & alternative predictions obtained **varying QCD scales or PDF sets**, or from **alternative MC generators**

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- signal systematic uncertainties:
  - scale variations uncertainties: **0.7~25%**
  - PS variation, different PDF sets
  - NLO EW corrections

Fit results

- BDT_{VH} outputs fitted both in a single (VH) or two-POI (WH, ZH) configurations
- additional measurements (not discussed) include 5 POI: V → leptons processes

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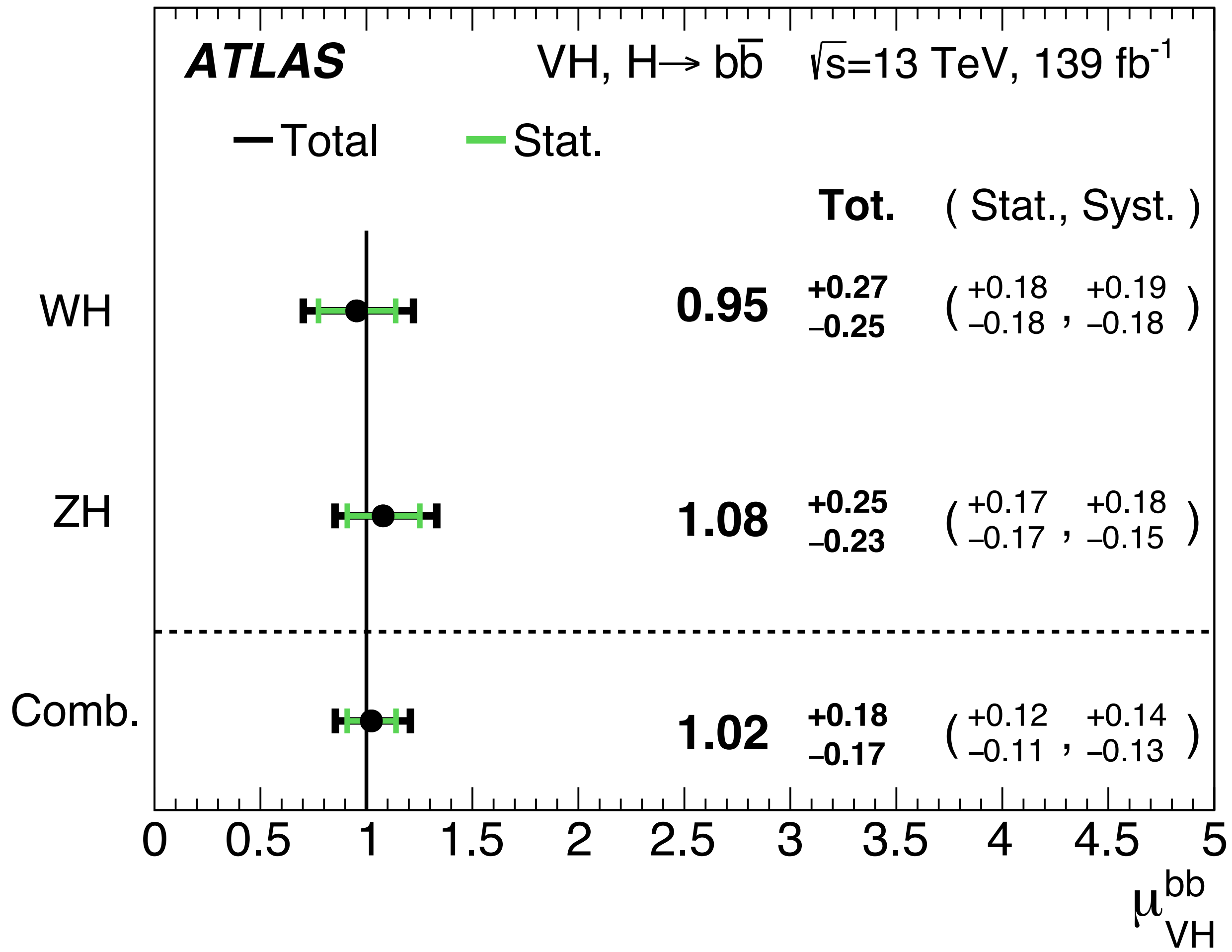
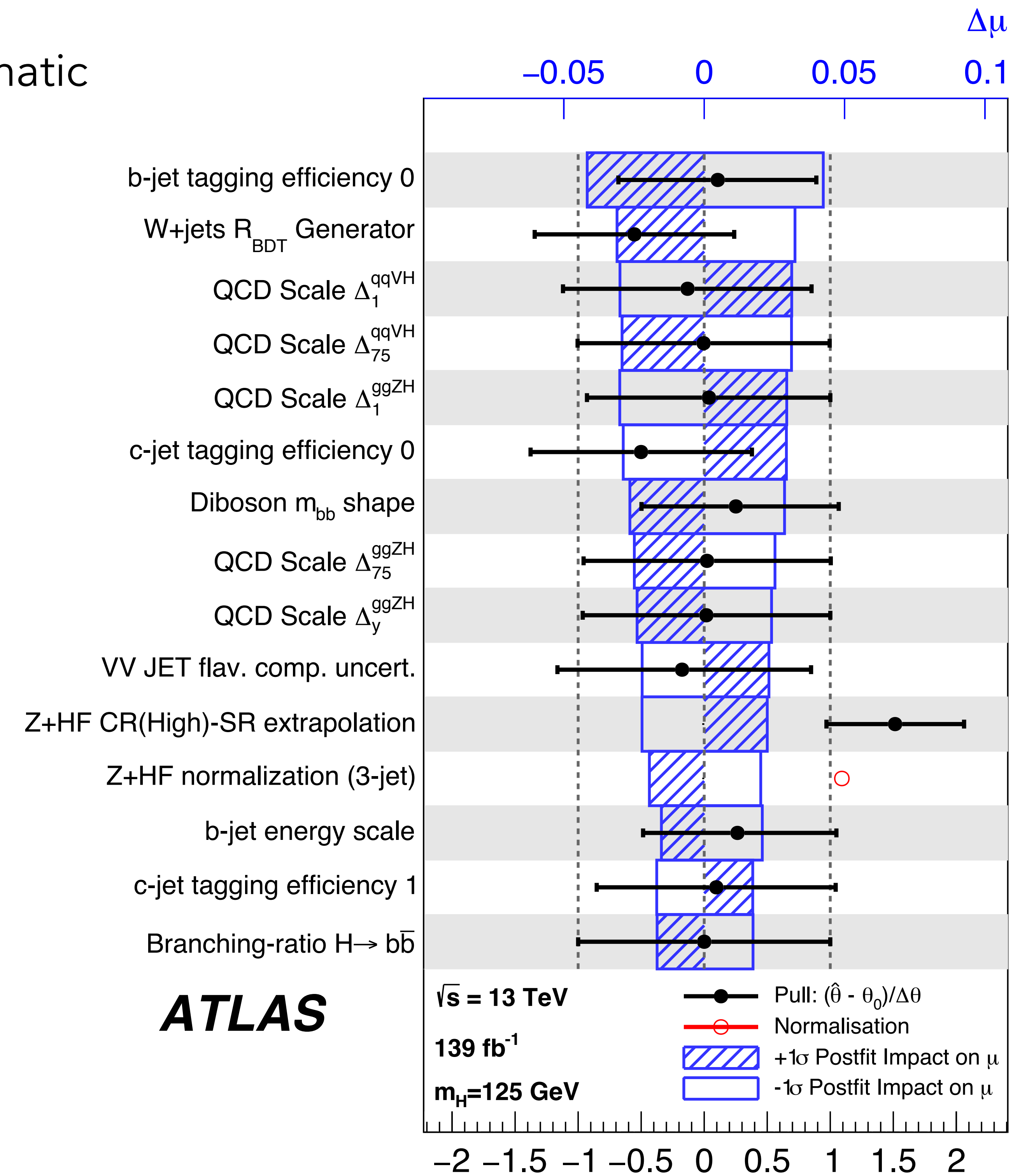


- background only hypotheses are rejected with obs. (exp.) significances of:
  - 4.0 (4.1) σ for the WH production mode
  - 5.3 (5.1) σ for the ZH channel
  - 6.7 (6.7) σ for the combined measurement of the three channels

Impact of systematic uncertainties on the results

- plot summarises the impact of top 15 systematic uncertainties on the VH combined fit



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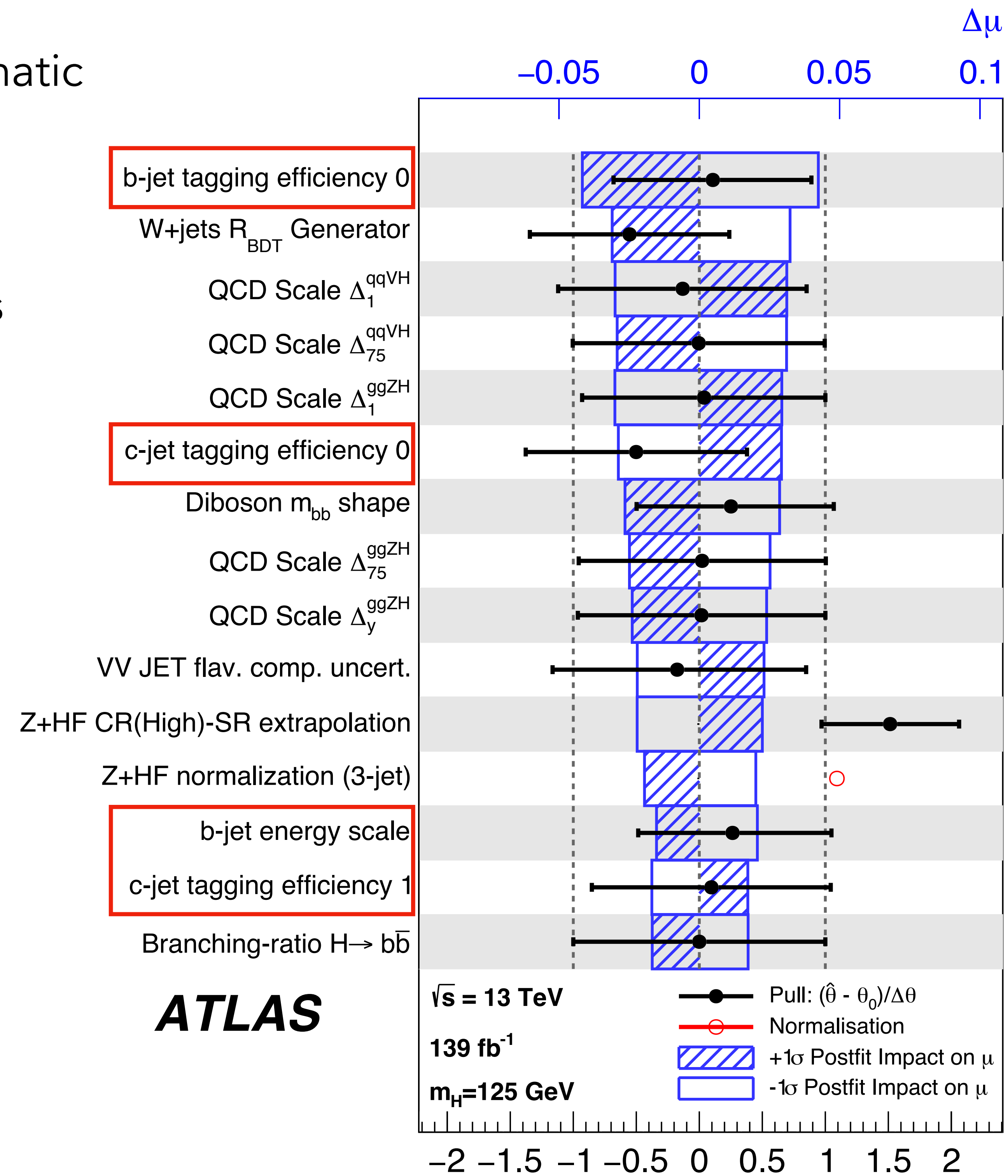

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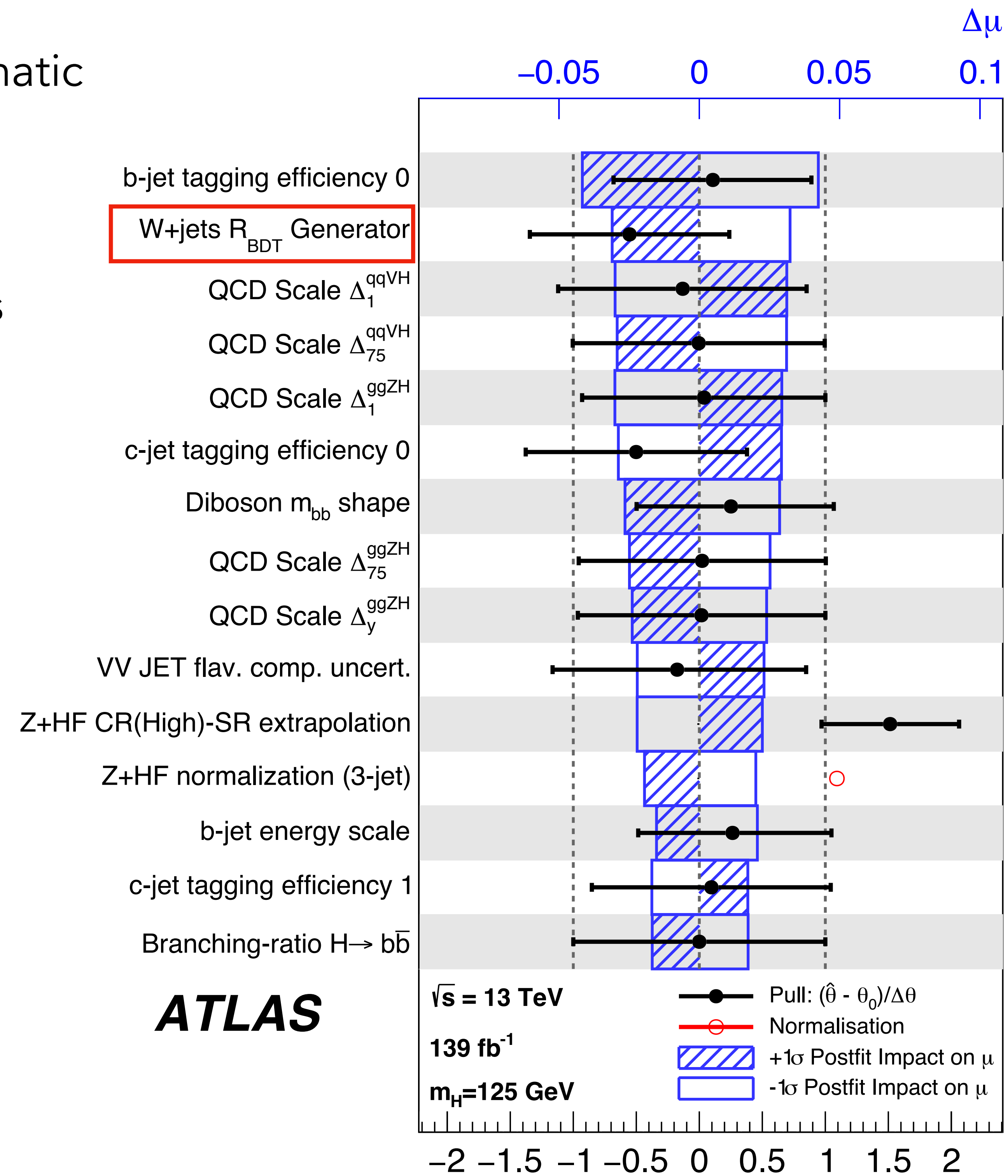

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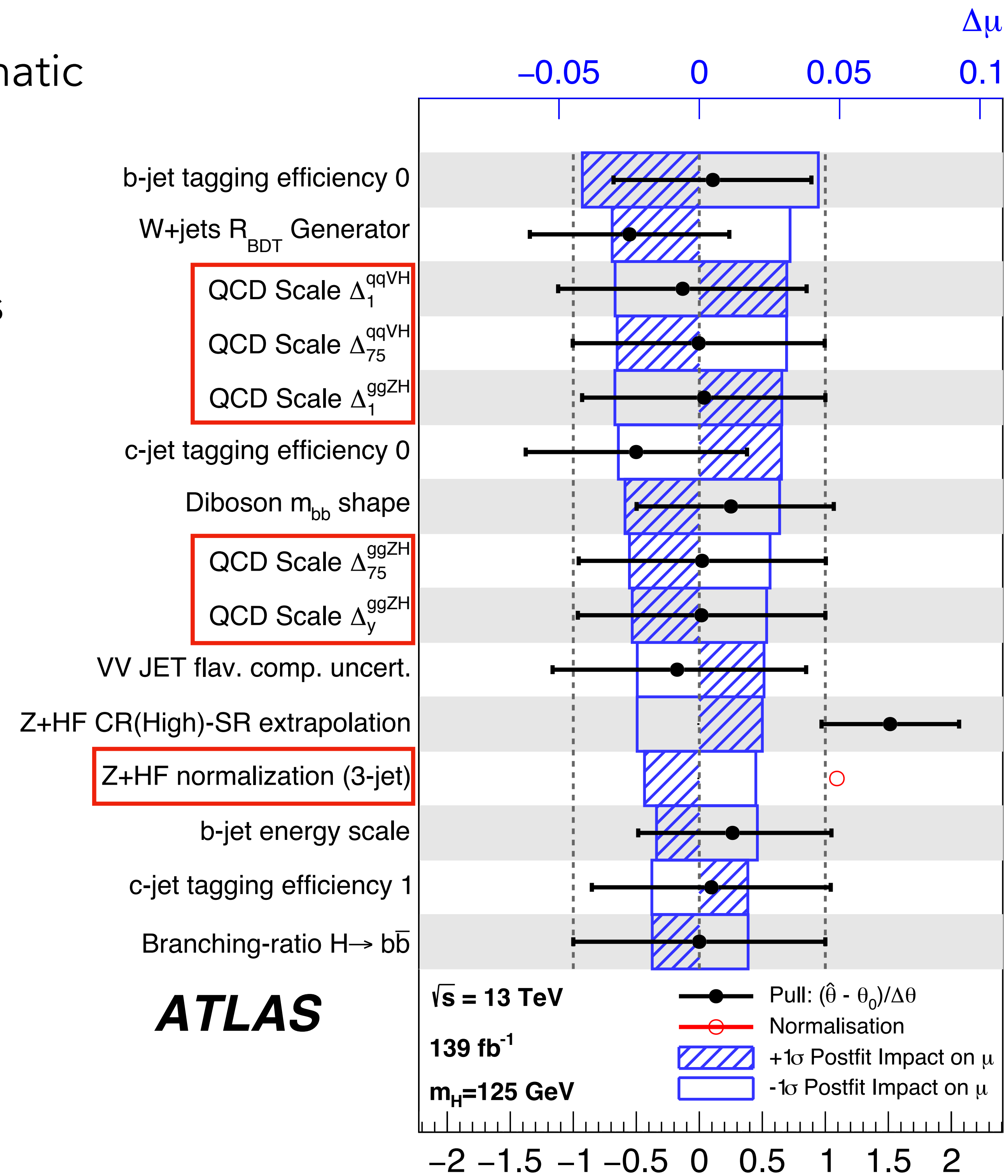
- second leading impact from the **comparison with alternative MC generators** for the background modelling in the 1l channel
- several signal modelling uncertainties among top ranked impacts:
  - large **scale uncertainties** on ggZH process, only known @ LO, causing migration of events
  - large **Z+HF normalisation factor** needed to correct known MC mis-modelling



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Conclusion

- lots of interesting results not covered for lack of time:
  - VHbb measurements interpretation in the Simplified Template Cross-section (STXS) framework
  - constraints on Effective Field Theories operators
  - boosted VH(bb) analysis: challenging regime requiring development of new reconstruction techniques

- space for improvements in both background, signal modelling & analysis strategy towards a unified legacy analysis
  - new ideas covered in F. Di Bello's talk:
    "Analysis and reconstruction techniques to improve VHbb measurements"

- References:
  - Resolved VH(bb) analysis: arXiv:2007.02873
  - Boosted VH(bb) analysis: arXiv:2008.02508

- Contact: guglielmo.frattari@cern.ch